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NAVAL AIR PROPULSION CENTER

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ROTOR FRAGMENT PROTECTION PROGRAM: STATISTICS ON AIRCRAFT GAS TURBINE ENGINE ROTOR FAILURES THAT OCCURRED IN U. S. COMMERCIAL AVIATION DURING 1979

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PROPULSION TECHNOLOGY AND PROJECT ENGINEERING DEPARTMENT

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INTRODUCTION

This report has been prepared as part of the Rotor Fragment Protection Program (RFPP), which is sponsored by the National Aeronautics and Space Administration (NASA)[1] and conducted by the Naval Air Propulsion Center (NAPC). The objective of the RFPP is to develop criteria for the design of devices that will be used on aircraft to protect occupants and the aircraft structure from the potentially lethal and devastating fragments that are generated by gas turbine engine rotor failures.

Presented in this report are statistics on gas turbine rotor failures that have occurred in U. S. commercial aviation during 1979. These statistics are based on data compiled from the Flight Standards Service Difficulty Reports (SDRs) that were published by the Department of Transportation, Federal Aviation Administration (FAA). The compiled data were analyzed to establish:

1. The incidence of rotor failures and the incidence of contained and uncontained[2] rotor fragments.

2. The distribution of rotor failures with respect to engine rotor component; i.e., fan, compressor or turbine rotors and their rotating attachments or appendages such as spacers and seals.

3. The type of rotor fragment (disk, rim or blade) typically generated at failure.

4. The cause of failure.

5. The type of engines involved.

6. The flight condition at the time of failure.

RESULTS

1. The data used for analysis are contained in APPENDIX A. The results of these analyses are shown in Figures 1 through 7.

a. Figure 1 shows that 157 rotor failures occurred in 1979. These rotor failures accounted for approximately 7.4% of the 2124 shutdowns experienced by the gas turbine powered U. S. commercial aircraft fleet during 1979.

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[1]NASA DPR C-41581-B, Mod. 8.

[2]An uncontained rotor failure is defined as a rotor failure that produces fragments which penetrate and escape the confines of the engine casing.

Rotor fragments were generated in 98 of the failures experienced and, of these, 18 (18.4% of the fragment producing failures) were uncontained. This represents an uncontained failure rate of 2.5 per million gas turbine engine powered aircraft flight hours, or 1.2 per million engine operation hours. Approximately 7.3 million and 21.5 million aircraft flight and engine operating hours, respectively, were logged by the U.S. commercial aviation fleet in 1979.

b. Figure 2 shows the distribution of rotor failures that produced fragments according to the engine component involved -- fan, compressor, turbine; the types of fragments that were generated; and the percentage of uncontained failures according to the type fragment generated. These data indicate that:

(1) The incidence of turbine-rotor-fragment-producing failures was approximately 2.4 times greater than that of compressor-rotor-fragment-producing failures; these corresponded to 62.2% and 26.5%, respectively, of the total number of rotor failures. Fan rotor failures accounted for 11.2% of the fragment producing failures experienced.

(2) Blade fragments were generated in 96.0% of the rotor failures; 15.9% of these were uncontained. The remaining rotor fragment failures (4.0%) produced rim and seal fragments, of which 100% and 50%, respectively, were uncontained.

c. Figure 3 shows the rotor failure distribution among the types of engines that were affected, and the total number of that type engine in use.

d. Figure 4 shows what caused the rotor failures to occur. Of the known causes of failure[1], the dominant causal factors were: (1) Foreign Object Damage (FOD) (36.8%); (2) Secondary causes (35.8%), and (3) Design and Life Prediction Problems (21.1%).

e. Figure 5 indicates the flight conditions that existed when the various rotor failures occurred. Approximately 68% of the 157 rotor failures occurred during takeoff and climb stages of flight. Approximately 69% of the rotor fragment producing failures, and 78% of the uncontained rotor failures, occurred during these same stages of flight. The highest percentage of uncontained rotor failures were experienced during takeoff (39%), and climb (39%). One uncontained failure was not included in the compilation because the cause and flight condition are unknown.

f. Figure 6 is a cumulative tabulation that describes the distribution of uncontained rotor failures according to fragment type, engine component involved, cause category and flight condition[2] for the years 1976 to 1979. This figure

[1]Because of the high percentage of unknown causes of rotor failure, the percentages were based on the total number of known causes.

[2]Takeoff and climb are defined as "High Power", all other conditions are defined as "Low Power".

is expanded yearly to include all subsequent uncontained rotor failures. These data indicate that: for "design and life prediction problems" the numbers of uncontained failures were approximately two times greater at "high" power than "low" power (namely 13 and 5); but for all other causes, the prevailing condition was "high power". Additional conclusions should become evident from this table with the accumulation of future data. One uncontained failure that occurred in 1979 was not included in the compilation because the failure cause and flight condition are unknown.

g. Figure 7 shows the annual incidence of uncontained rotor failures in commercial aviation for the years 1962 through 1979. During 1979, the incidence of uncontained rotor failure decreased by one over the previous year, 1978. Over the past five years, 1975 through 1979, an average of 16.4 uncontained rotor failures per year have occurred. During this same time period, the rate of uncontained rotor failures has remained relatively constant at an average of approximately one per million engine operating hours.

CONCLUSIONS

1. The incidence of rotor failure and uncontained failure is significantly high enough to warrant continuation of the experimental and analytical efforts that constitute the RFPP.

2. Of all types of fragments generated at rotor failure, disk and fan blade fragments, because of their size and high energy content, continue to be the threat that must be addressed in the RFPP.

3. It appears that causes such as FOD, structural life and integrity prediction, and secondary effects, are primarily responsible for most of the rotor failures that occur. Progress in the ability to predict structural life is being made through numerous programs sponsored both by Government agencies and by industry. The capability to reduce the causes of failures from secondary effects, such as bearing or seal failures, also is being addressed through technological programs. However, causes due to FOD still appear to be beyond the control or scope of present technology.

INCIDENCE OF ROTOR FAILURE IN U.S. COMMERCIAL AVIATION 1979

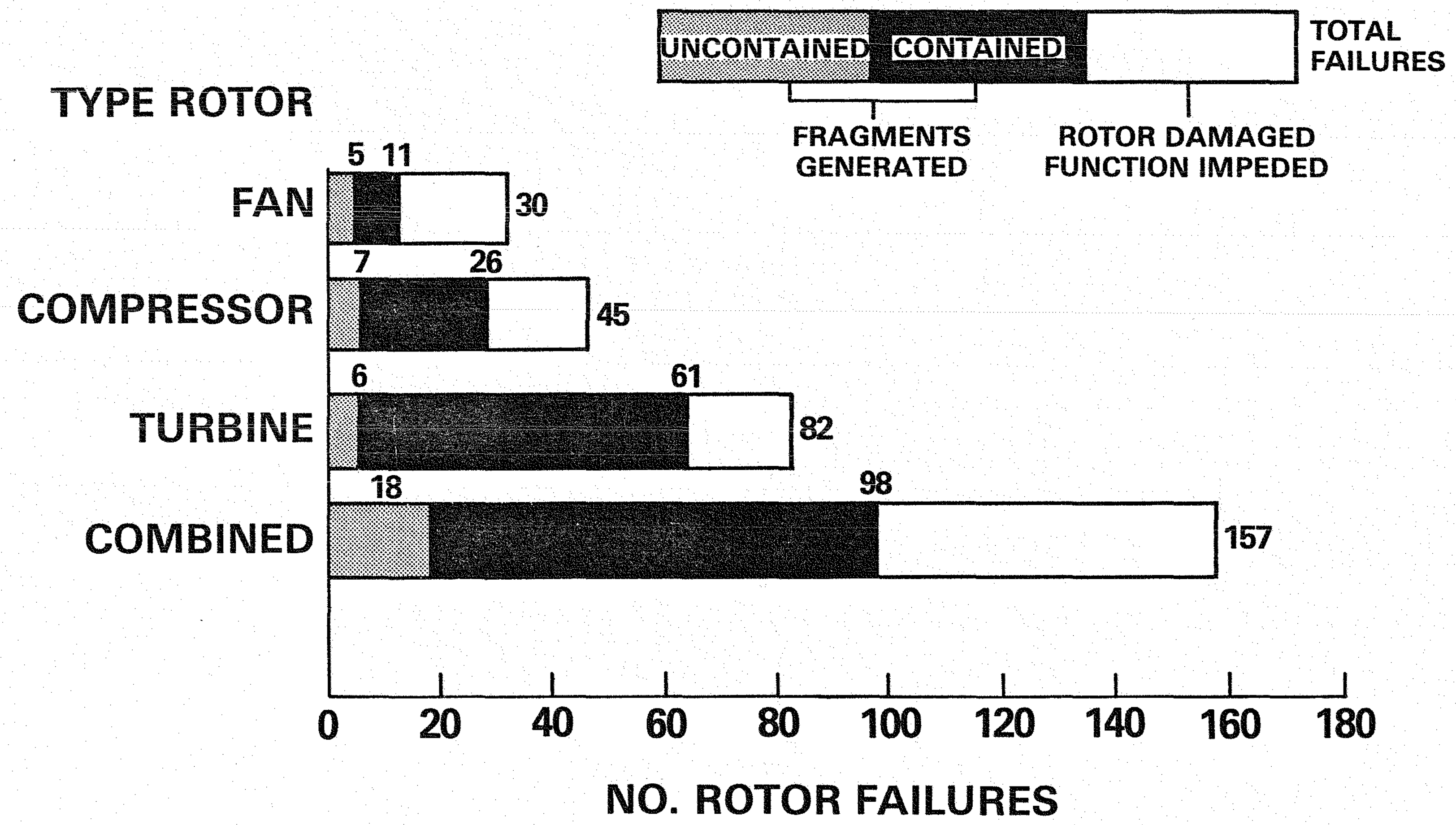


FIGURE 1

NAPC-PE-80

COMPONENT AND FRAGMENT TYPE DISTRIBUTIONS FOR CONTAINED AND UNCONTAINED ROTOR FAILURES[1] — 1979

ENGINE ROTOR COMPONENT	TYPE OF FRAGMENT GENERATED									
	DISK		RIM		BLADE		SEAL		TOTALS	
	TF	UCF	TF	UCF	TF	UCF	TF	UCF	TF	UCF
FAN	0	0	0	0	11	5	0	0	11	5
COMPRESSOR	0	0	2	2	22	4	2	1	26	7
TURBINE	0	0	0	0	61	6	0	0	61	6
TOTALS	0	0	2	2	94	15	2	1	98	18

(1) FAILURES THAT PRODUCED FRAGMENTS
TF — TOTAL FAILURES
UCF — UNCONTAINED FAILURES

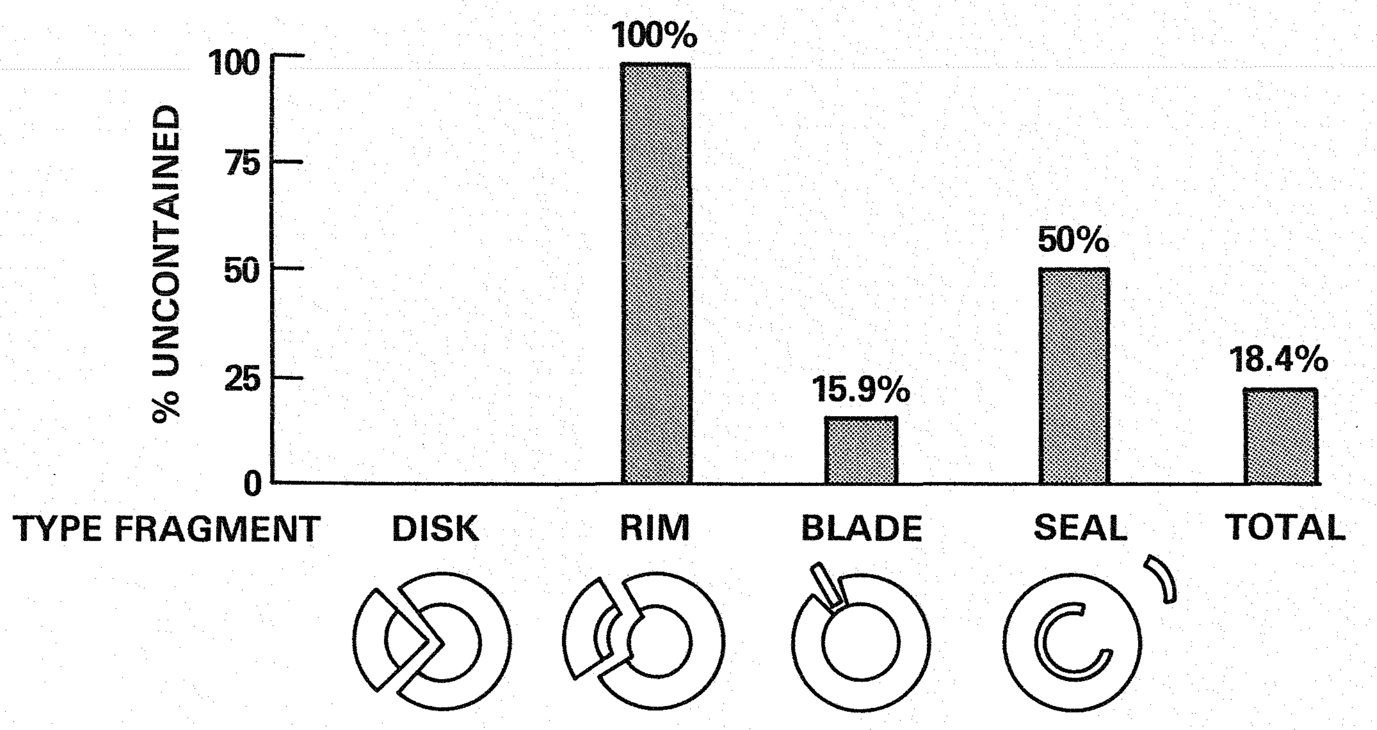
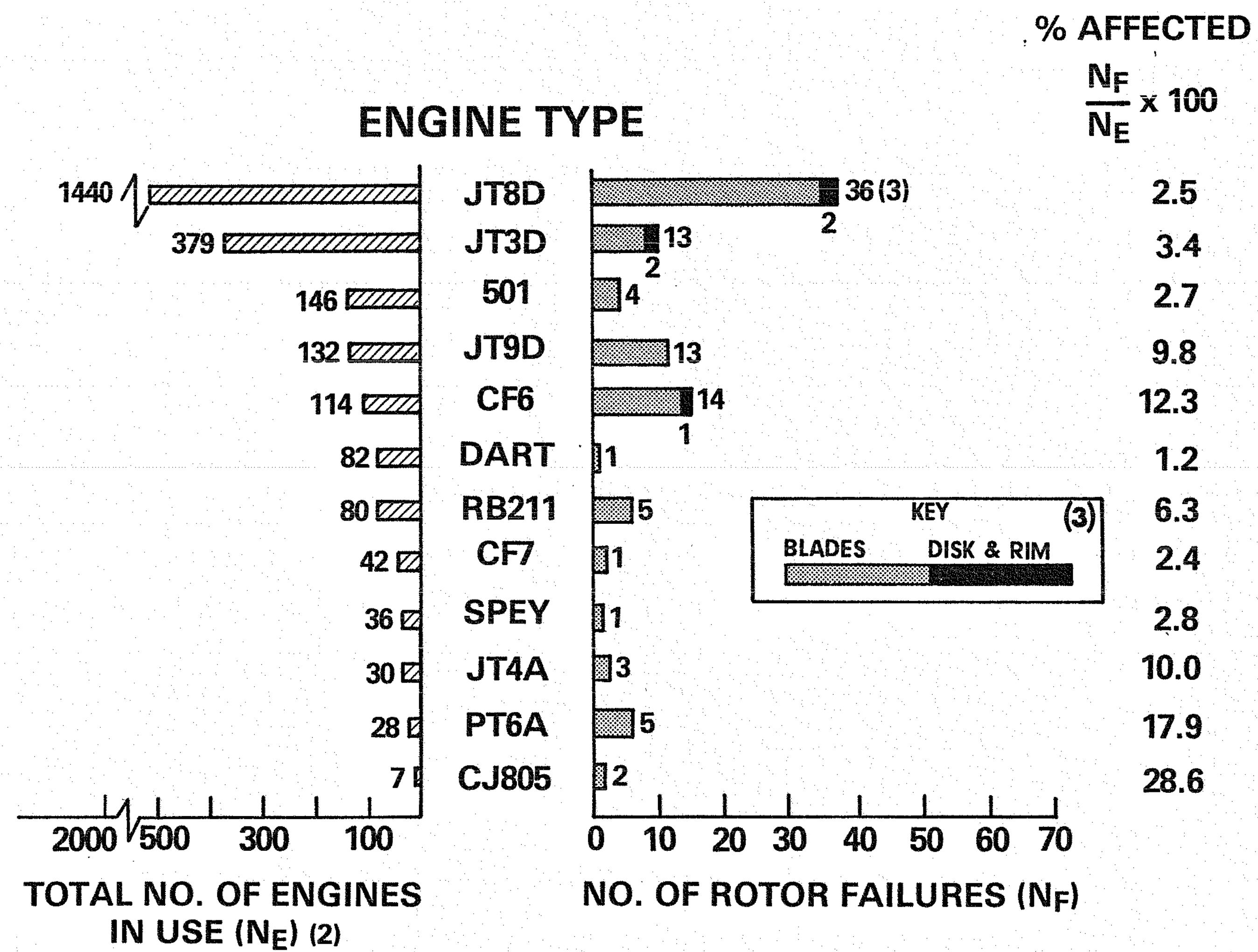


FIGURE 2

NAPC-PE-80

THE INCIDENCE OF ROTOR FAILURE(1) IN U.S. COMMERCIAL AVIATION ACCORDING TO ENGINE TYPE AFFECTED — 1979



NOTES: (1) FAILURES THAT PRODUCED FRAGMENTS
(2) YEARLY AVG. OF AIRCRAFT IN USE AT END OF EACH MONTH
(3) 2 SEAL/SPACER FAILURES INCLUDED IN DISK/RIM COMPILATION

FIGURE 3

ROTOR FAILURE CAUSE CATEGORIES — 1979

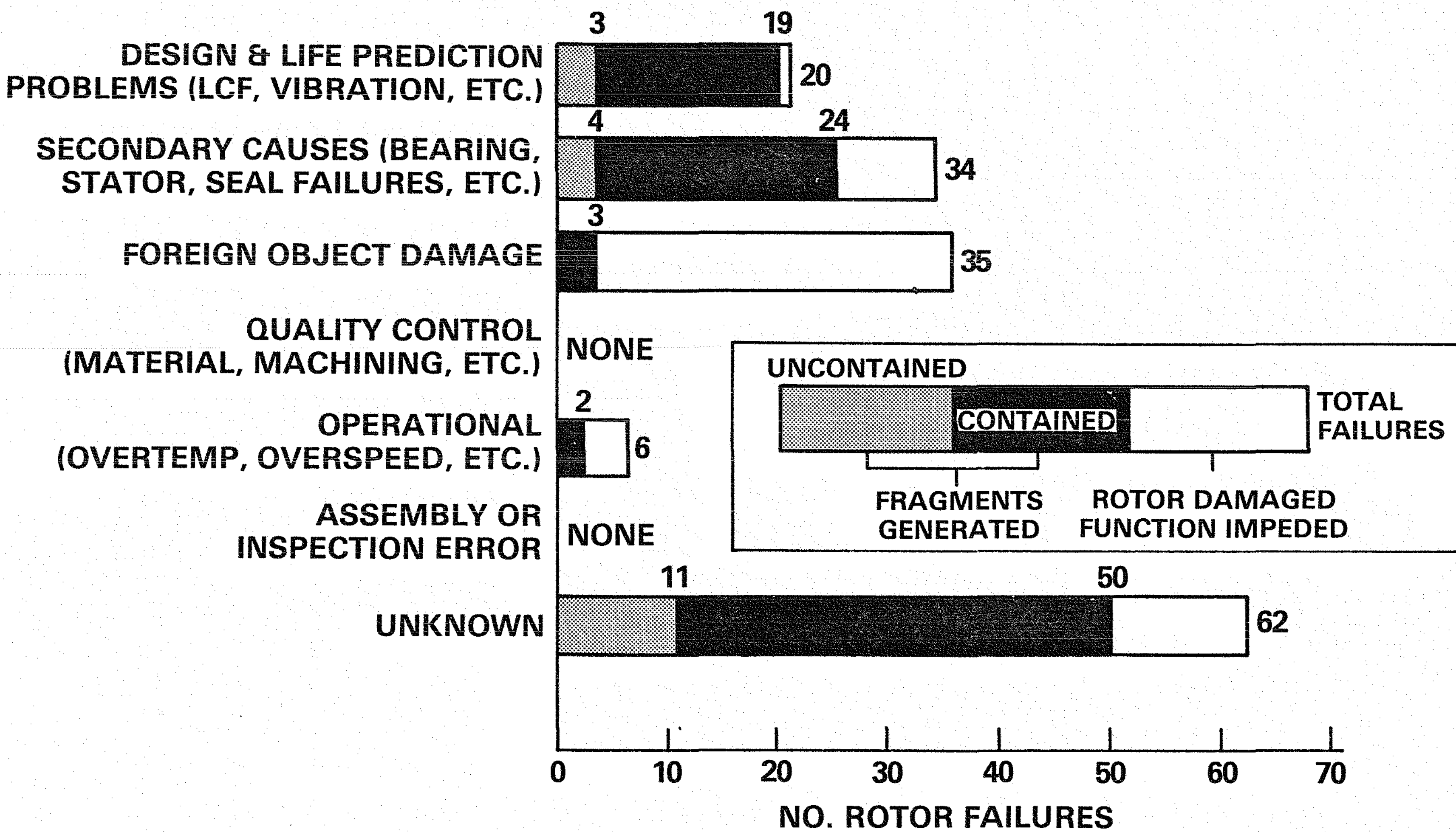


FIGURE 4

NAPC-PE-80

FLIGHT CONDITION AT ROTOR FAILURE — 1979

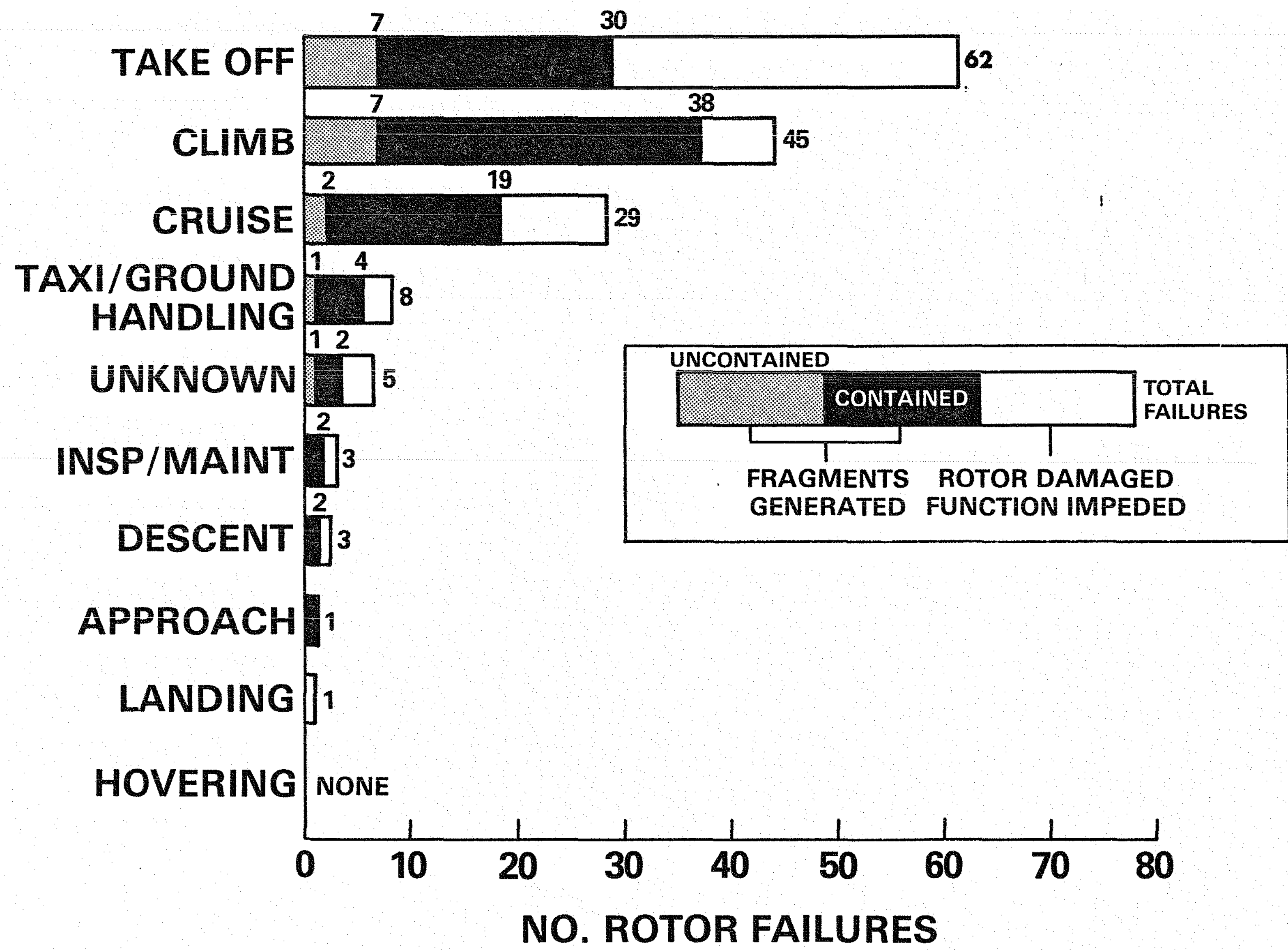


FIGURE 5

NAPC-PE-80

UNCONTAINED ROTOR FAILURE DISTRIBUTIONS ACCORDING TO CAUSE AND FLIGHT CONDITION[1] 1976 — 1979

		DESIGN & LIFE PRED PROBLEMS		SECONDARY CAUSES		FOREIGN OBJECT DAMAGE		QUALITY CONTROL		UNKNOWN		SUBTOTALS		
TYPE OF FRAGMENT GENERATED	ENGINE ROTOR COMPONENT	HIGH POWER	LOW POWER	HIGH POWER	LOW POWER	HIGH POWER	LOW POWER	HIGH POWER	LOW POWER	HIGH POWER	LOW POWER	HIGH POWER	LOW POWER	TOTALS
DISK	FAN											0	0	
	COMPRESSOR	1										1	0	
	TURBINE		2									0	2	3
RIM	FAN											0	0	
	COMPRESSOR	2				1				2	1	5	1	
	TURBINE							1				1	0	7
BLADE	FAN	3	1	2		3	1	2		3		13	2	
	COMPRESSOR	5		2						7		14	0	
	TURBINE	1	2	10	2					4	3	15	7	51
SEAL	FAN											0	0	
	COMPRESSOR	1								1	1	2	1	
	TURBINE			2						1		3	0	6
SUBTOTALS		13	5	16	2	4	1	3	0	18	5	54	13	
TOTALS		18		18		5		3		23		67		67

(1) TAKEOFF AND CLIMB ARE DEFINED AS "HIGH POWER," AND ALL OTHER CONDITIONS ARE DEFINED AS "LOW POWER"

FIGURE 6

THE INCIDENCE OF UNCONTAINED ROTOR FAILURES IN U.S. COMMERCIAL AVIATION 1962 — 1979

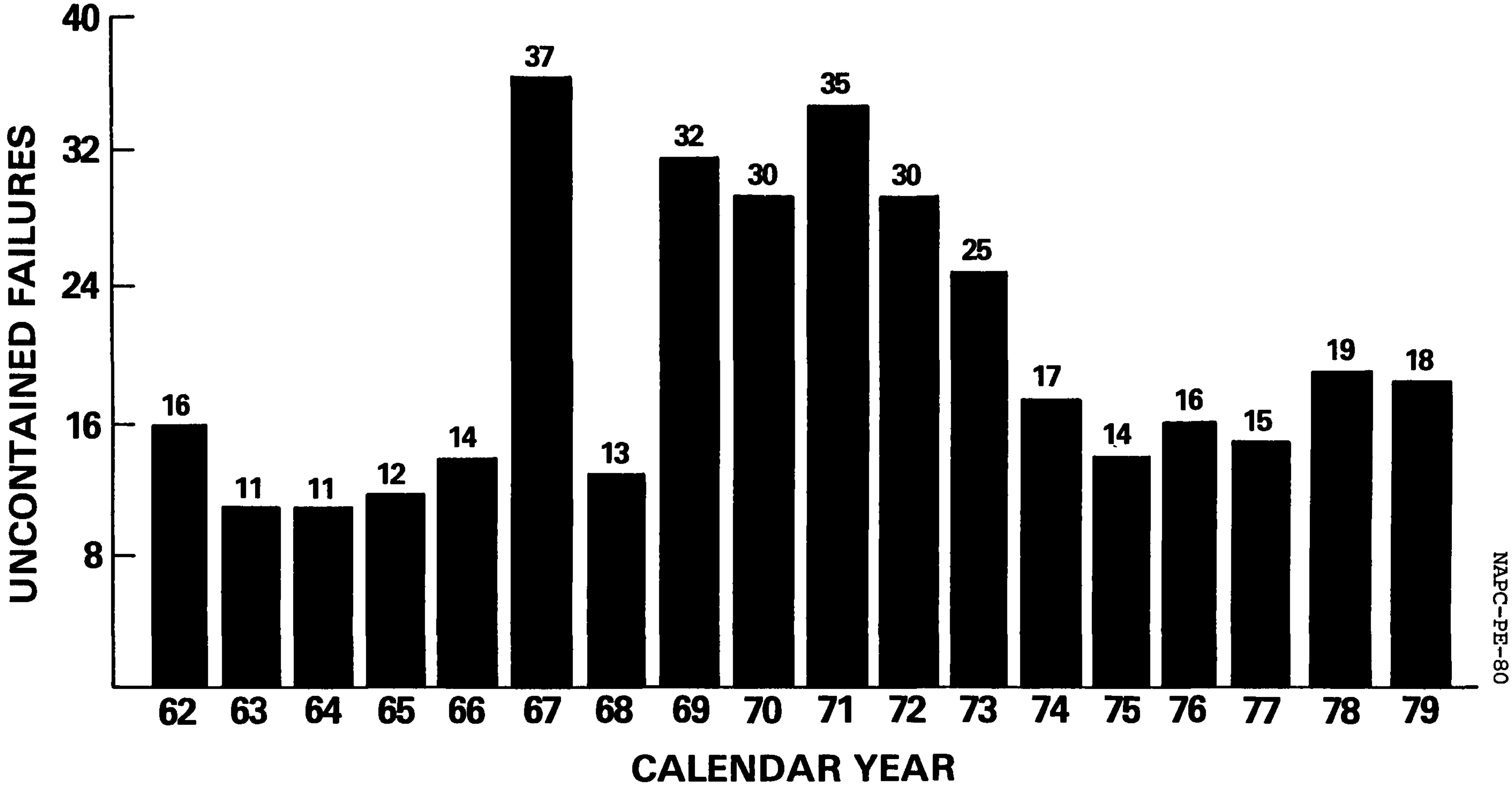


FIGURE 7

APPENDIX A

Data on Rotor Failures in U. S. Commercial Aviation for 1979. Compiled from the Federal Aviation Administration Service Difficulty Reports.

DATA COMPILATION KEY:

Component Code:

F - Fan

C - Compressor

T - Turbine

Fragment Type Code:

D - Disk

R- Rim

B - Blade

S - Seal

N - None

Cause Code:

1 - Design and Life Prediction Problems

2 - Secondary Causes

3 - Foreign Object Damage

4 - Quality Control

5 - Operational

6 - Assembly or Inspection Error

7 - Unknown

Containment Condition Code:

C - Contained

U - Not Contained

N - No Fragments Generated

Flight Condition Code:

1 - Insp/Maint

2 - Taxi/Grnd Hdl

3 - Takeoff

4 - Climb

5 - Cruise

6 - Descent

7 - Approach

8 - Landing

9 - Hovering

10 - Unknown

CHARACTERISTICS OF ROTOR FAILURES - 1979

SDR NO.	DATE	SUBMITTER	AIRCRAFT	ENGINE	COMPONENT	FRAGMENT TYPE	CAUSE	CONTAINMENT CONDITION	FLIGHT CONDITION
01239027	1/4	OZA	FH227	DART	T	B	1	C	2
01319023	1/7	AAA	DC9	JT8D	T	B	7	C	3
02129032	1/18	EIAS	DC9	JT8D	C	B	1	C	5
02279034	2/4	AAL	DC10	CF6	T	B	7	C	4
03029031	3/2	CAPS	DC8	JT4	T	B	7	C	5
03059030	2/7	NAL	B727	JT8D	F	B	1	C	5
03069026	2/8	AAL	B707	JT3D	F	B	7	U	3
03069027	2/7	OZA	DC9	JT8D	C	B	2	C	3
03079029	2/3	AAA	DC9	JT8D	T	B	7	C	3
03079030	2/1	EAL	DC9	JT8D	C	B	2	C	3
03089033	2/2	AAA	DC9	JT8D	T	B	1	C	4
03099032	2/13	NAL	B727	JT8D	F	B	1	C	3
03149030	2/8	EIAS	DC9	JT8D	T	B	7	C	4
03159024	2/20	SFSX	CV580	501	T	B	1	C	5
03159033	2/11	UAL	B747	JT9D	F	B	2	U	4
03169028	2/17	OZA	DC9	JT8D	T	B	1	C	4

CHARACTERISTICS OF ROTOR FAILURES - 1979

SDR NO.	DATE	SUBMITTER	AIRCRAFT	ENGINE	COMPONENT	FRAGMENT TYPE	CAUSE	CONTAINMENT CONDITION	FLIGHT CONDITION
03199024	2/14	BNF	B727	JT8D	T	B	2	C	10
03199025	2/24	TXI	DC9	JT8D	T	B	7	C	3
03229013	2/28	OZA	DC9	JT8D	C	B	2	C	2
03289024	3/5	CAPS	DC8	JT3D	T	B	1	C	4
04029030	3/7	EAL	DC9	JT8D	C	B	2	C	5
04039030	3/15	TIAS	DC10	CF6	C	R	7	U	3
04059029	3/17	TWA	B707	JT3D	C	B	2	C	3
04059030	2/27	DAL	DC9	JT8D	C	S	7	C	4
04059031	3/3	DAL	DC9	JT8D	T	B	7	U	5
04059033	3/17	TWA	L1011	RB211	T	B	7	C	5
04069031	3/11	CAPS	DC8	JT3D	T	B	7	C	7
04099036	2/7	FECZ	MD20	CF700	F	B	7	C	3
04109035	3/20	TWA	L1011	RB211	C	B	2	C	5
04129037	3/25	TWA	L1011	RB211	C	B	2	C	5
04169040	3/13	AAA	BA111	SPEY	T	B	7	C	4
04239034	3/20	EAL	B727	JT8D	T	B	5	C	3
04249016	4/24	RDLS	DC8	JT3D	T	B	7	C	5
04259029	4/4	PCTC	CV990	CJ805	T	B	2	C	4

CHARACTERISTICS OF ROTOR FAILURES - 1979

SDR NO.	DATE	SUBMITTER	AIRCRAFT	ENGINE	COMPONENT	FRAGMENT TYPE	CAUSE	CONTAINMENT CONDITION	FLIGHT CONDITION
04269033	4/7	TWA	B747	JT9D	C	B	1	C	5
04279038	4/10	TIAS	L382	501	C	B	3	C	6
04279040	4/10	SBWS	B747	JT9D	T	B	2	C	3
05039013	4/9	EIAS	DC8	JT3D	T	B	7	C	4
05079024	4/20	BNF	B747	JT8D	T	B	2	C	3
05089027	4/20	TWA	L1011	RB211	T	B	1	C	4
05099017	4/26	PAA	B727	JT9D	T	B	2	C	4
05169023	4/27	SPAT	CV340	501	T	B	2	C	5
05169025	4/15	NOMC	CV990	CJ805	C	B	3	C	6
05179022	4/28	PAA	B707	JT3D	C	R	7	U	2
05309021	5/14	AWI	DC9	JT8D	T	B	7	C	5
06019014	5/20	FTLS	DC8	JT3D	C	B	7	C	4
06049022	5/21	SBWS	B747	JT9D	T	B	2	C	4
06059022	5/22	CAL	DC10	CF6	T	B	7	C	3
06069022	5/23	AW	DC9	JT8D	T	B	7	C	4
06139023	5/31	NAL	DC10	CF6	T	B	7	C	4
06189028	5/1	GWAT	SD330	PT6	T	B	7	U	3
06199024	6/6	AAL	B727	JT8D	T	B	7	C	4

CHARACTERISTICS OF ROTOR FAILURES - 1979

SDR NO.	DATE	SUBMITTER	AIRCRAFT	ENGINE	COMPONENT	FRAGMENT TYPE	CAUSE	CONTAINMENT CONDITION	FLIGHT CONDITION
06279027	6/14	AAL	B727	JT8D	T	B	2	C	4
06299013	6/15	GIAX	B707	JT3D	T	B	5	C	3
06299017	6/17	TWA	L1011	RB211	C	B	7	C	5
07029023	6/18	UAL	B747	JT9D	F	B	2	U	4
07059026	6/13	ZIAX	DC8	JT3D	T	B	7	C	3
07069021	3/27	UAL	DC8	JT3D	T	B	7	U	4
07099016	6/25	PAI	B737	JT8D	F	B	7	U	3
07109024	6/21	TWA	B727	JT8D	T	B	7	C	4
07109026	6/20	NWA	B727	JT9D	F	B	7	U	3
07119023	6/27	EIAS	DC8	JT3D	T	B	7	C	2
07239022	7/7	TWA	DC9	JT8D	C	B	2	C	4
07279025	7/14	TWA	B747	JT9D	T	B	7	C	4
08029020	7/11	RAIX	DC8	JT4A	T	B	2	C	4
08079028	7/22	UAL	DC10	CF6	T	B	1	C	4
08149026	7/23	UAL	DC10	CF6	C	B	7	C	4
08149031	8/2	CAL	B727	JT8D	F	B	1	C	3
08179032	8/6	TWA	B707	JT3D	C	B	2	C	4

CHARACTERISTICS OF ROTOR FAILURES - 1979

SDR NO	DATE	SUBMITTER	AIRCRAFT	ENGINE	COMPONENT	FRAGMENT TYPE	CAUSE	CONTAINMENT CONDITION	FLIGHT CONDITION
08239029	8/7	ACA	B737	JT8D	C	B	1	U	3
08249023	8/2	HAL	DC9	JT8D	T	B	2	C	3
08279023	8/10	NWA	B747	JT9D	T	B	1	C	4
08279024	8/9	NWA	B747	JT9D	T	B	7	C	3
08309029	8/15	SPAT	CV580	501	T	B	7	C	4
08309030	8/16	RAIZ	DC8	JT4A	T	B	2	C	5
08309031	8/13	PAI	B737	JT8D	T	B	7	C	4
09189025	9/4	NWA	B727	JT8D	F	B	7	C	3
09219031	9/2	TWA	B747	JT9D	C	B	7	U	4
09279031	9/8	RAHT	SD330	PT6A	T	B	7	C	1
09279034	9/7	RMAT	DHC7	PT6A	T	B	7	C	4
09289020	9/9	WAL	DC10	CF6	C	B	7	U	4
10039011	9/17	AAL	B727	JT8D	T	B	7	C	4
10059033	9/15	CAL	DC10	CF6	C	B	1	U	4
10119038	9/25	TIAS	DC10	CF6	C	B	1	C	4
10129033	9/15	AAA	B727	JT8D	T	B	7	C	5
10179038	9/28	CAL	DC10	CF6	T	B	7	C	4
10179039	9/21	GWAT	SHSD3	PT6A	T	B	7	C	1

CHARACTERISTICS OF ROTOR FAILURES - 1979

SDR NO	DATE	SUBMITTER	AIRCRAFT	ENGINE	COMPONENT	FRAGMENT TYPE	CAUSE	CONTAINMENT CONDITION	FLIGHT CONDITION
10199027	10/19	NWA	DC10	JT9D	F	B	3	C	3
10309039	10/7	PAA	B747	JT9D	T	B	7	C	5
11029022	10/5	DAL	DC9	JT8D	T	B	2	U	4
11099031	10/26	SWA	B737	JT8D	T	B	1	C	3
11169026	10/29	CAL	DC10	CF6	T	B	7	C	3
11209027	10/27	EAL	B727	JT8D	C	S	1	U	3
12129036	11/13	ANE	DHC6	PT6A	T	B	2	U	5
12149036	11/29	NAL	DC10	CF6	C	B	7	C	5
01140038	12/22	SWA	B737	JT8D	T	B	1	C	3
01170034	12/20	UAL	DC10	CF6	T	B	7	C	3
01170035	12/21	WAL	DC10	CF6	T	B	7	U	10

CHARACTERISTICS OF ROTOR FAILURES - 1979

SDR NO.	DATE	SUBMITTER	AIRCRAFT	ENGINE	COMPONENT	CAUSE	FLIGHT CONDITION
02129020	2/19	HAL	DC9	JT8D	F	3	3
02209032	1/27	TWA	B727	JT8D	C	3	3
01199027	1/2	TWA	B747	JT9D	C	2	10
03059029	2/9	TWA	B727	JT8D	T	2	4
03069026	2/8	AAL	B707	JT3D	F	3	3
03069028	2/14	NAL	B727	JT8D	F	3	3
03149033	2/17	TWA	B747	JT9D	C	3	5
03159030	2/18	DAL	B727	JT8D	C	3	3
03169027	2/17	AWI	DC9	JT8D	T	7	3
03169032	2/20	TWA	L1011	RB211	C	3	3
03199021	2/23	TIAS	L382	501	C	3	3
03219034	1/15	MWCT	CV600	DART	T	2	2
04029031	3/10	NAL	B727	JT8D	C	3	5
04109034	3/20	TWA	B707	JT4	T	7	3
04179037	3/20	AAA	DC9	JT8D	T	5	2
04259032	4/5	PAI	B737	JT8D	F	3	3
04269030	4/1	PCTC	CV990	CJ805	F	2	5

CHARACTERISTICS OF ROTOR FAILURES - 1979

SDR NO.	DATE	SUBMITTER	AIRCRAFT	ENGINE	COMPONENT	CAUSE	FLIGHT CONDITION
04279039	4/10	ACA	L188	501	T	2	5
05099012	4/26	TIAS	L382	501	T	3	10
05099016	4/22	AAA	B727	JT8D	C	7	3
05169024	4/27	AIAX	L382	501	C	7	5
05179024	5/19	AAA	DC9	JT8D	F	3	3
05259025	5/10	AIAX	L382	501	T	7	10
06019016	5/14	AAA	B727	JT8D	C	3	3
06059023	5/20	FTLS	DC8	JT3D	F	3	3
06059025	5/23	SOU	DC9	JT8D	T	7	4
06229153	6/22	WAL	B727	JT8D	F	3	3
06279025	6/14	AAL	B727	JT8D	F	3	3
06279031	6/10	RAHT	SD330	PT6	T	2	2
07199025	4/27	SPAT	CV340	501	T	1	5
07239021	7/2	AAA	DC9	JT8D	T	7	3
07249026	7/2	OZA	DC9	JT8D	T	5	5
07319020	7/13	RANT	STC262	PT6A	C	5	4
07319025	7/31	RANT	STC262	PT6A	T	2	4

CHARACTERISTICS OF ROTOR FAILURES - 1979

SDR NO.	DATE	SUBMITTER	AIRCRAFT	ENGINE	COMPONENT	CAUSE	FLIGHT CONDITION
08019018	7/19	NAL	DC10	CF6	T	2	3
08029019	7/18	NAL	DC10	CF6	T	2	4
08139029	7/24	FAL	B737	JT8D	F	3	8
08169020	8/5	CRAT	CV580	501	C	3	3
08179010	8/17	FAL	B737	JT8D	F	3	3
08249024	7/28	BNF	B727	JT8D	C	3	5
08319030	8/13	AAA	DC9	JT8D	C	7	3
09049028	8/17	PAI	B727	JT8D	F	3	3
09149011	8/24	OZA	DC9	JT8D	F	3	3
09179027	8/27	CAL	B727	JT8D	T	7	1
09249057	9/24	AAIX	B720	JT3D	T	7	3
09279030	7/10	RAHT	SD330	PT6A	T	5	2
10029022	8/29	AAIX	B720	JT3C	T	7	3
10099036	9/15	CAL	DC10	CF6	F	3	6
10119039	8/24	AAA	DC9	JT8D	C	3	3
10199037	9/30	UAL	B747	JT9D	F	3	3
10229035	10/2	UAL	B727	JT8D	T	2	5
10239038	10/3	TWA	B707	JT3D	F	3	3

CHARACTERISTICS OF ROTOR FAILURES - 1979

SDR NO.	DATE	SUBMITTER	AIRCRAFT	ENGINE	COMPONENT	CAUSE	FLIGHT CONDITION
10299030	10/12	AAL	B727	JT8D	C	3	3
11029021	10/16	TIAS	L188	501	C	3	3
11079034	10/23	TWA	B707	JT3D	C	3	4
11029021	11/2	TIAS	L188	501	C	7	3
12069032	11/14	TWA	B727	JT8D	F	3	4
01180034	12/31	NAL	DC10	CF6	F	3	5
01230037	12/26	UAL	DC8	JT3D	F	3	3

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents statistical information relating to the number of gas turbine engine rotor failures which occurred during 1979 in commercial aviation service use. The predominant failure mode involved blade fragments, 84 percent of which were contained. No uncontained disk failures occurred and although fewer rotor rim and seal failures occurred, 100 percent and 50 percent, respectively, were uncontained. Sixty-eight percent of the 157 rotor failures occurred during the take-off and climb stages of flight.

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